pond to an $(m-k-1)$-flat at infinity, and the complete orthogonal treatment subgroup of order s^{m-k} can be readily written down, as explained above, from the equations to the k pencils of $(m-1)$-flats of which the k independent $(m-2)$-flats at infinity, having the $(m-k-1)$-flat at infinity as their common intersection, are the vertices. In fact, the effect subgroup of order s^k would be obtained by taking the product of the k effect subgroups, each of order s, corresponding to the k independent $(m-2)$-flats at infinity. If any effect subgroup of order s^k is taken as an alias subgroup, and all its elements set equal to the identity, the complete orthogonal treatment subgroup comprises a set of s^{m-k} treatment combinations appropriate for an arrangement in $1/s^k$ replicate. Each effect has then s^k aliases which are obtained by multiplication of one of its names by elements of the alias subgroup. In terms of parallel pencils of s $(m-1)$-flats, each corresponding to $s-1$ degrees of freedom for a main effect or interaction, it would follow that the alias subgroup of pencils will consist of $s^{k-1}+s^{k-2}+\ldots+s^2+s+1$ pencils, and the remaining $s^k(s^{m-k-1}+s^{m-k-2}+\ldots+s^2+s+1)$ pencils are divisible into $s^{m-k-1}+s^{m-k-2}+\ldots+s^2+s+1$ alias sets of pencils, each set containing s^k pencils.

As an illustrative example, let us consider a 4^4 design in $1/4^2$ replicate. Then one such design is obtained by taking the five pencils of 3-flats, *viz.* $x+2y+2z=0,1,2,3$; $y+2z+2w=0,1,2,3$; $x+3y+2w=0,1,2,3$; $x+z+3w=0,1,2,3$; and $x+y+3z+w=0,1,2,3$, where 0, 1, 2, 3 denote respectively the elements $\alpha_0, \alpha_1, \alpha_2, \alpha_3$ of $GF(2^2)$, as the alias subgroup of pencils, to which corresponds the alias subgroup of order 16 given by

$I, AB^2C^2, A^2B^3C^3, A^3BC, BC^2D^2, B^2C^3D^3, B^3CD, AB^3D^2, A^2BD^3, A^3B^2D, ACD^3, A^2C^2D, A^3C^3D^2, ABC^3D, A^2B^2CD^2, A^3B^3C^2D^3$.

The complete orthogonal treatment subgroup to be used is

$I, ac^3d^3, a^2cd, a^3c^2d^2, bcd^2, abc^2d, a^2bd^3, a^3bc^3, b^2c^3d^3, ab^2c, a^2b^2c^3d^2, a^3b^2d, b^3c^3d, ab^3d^2, a^2b^3c^2, a^3b^3cd^3$,

which is obtained by taking the 16 treatment combinations corresponding to the 16 points lying on the 2-flat given by the equations

$$x+2y+2z=0 \text{ and } y+2z+2w=0.$$

Here the alias subgroup of pencils consists of the above 5 pencils, and the remaining $4^2(4+1)$ pencils of 3-flats are divisible into 5 alias sets of pencils, each set containing 4^2 pencils. It would be observed that the $1/4^2$ replicate of a 4^4 design gives main effects and two-factor interactions, or pairs of two-factor interactions, in some alias sets, and cannot, therefore, be considered to be of practical value unless two-factor interactions are ignored as of no importance.

For full details, the interested reader is referred to the author's paper on the subject to be published shortly elsewhere.

1. Finney, D. J., "The Fractional Replication of Factorial Arrangements," *Annals of Eugenics*, 1945, **12**, 291–301. 2. Bose, R. C., and Kishen, K., "On the Problem of Confounding in the General Symmetrical Factorial Design," *Sankhya*, 1940, **5**, Part 1, 21–36. 3. Robert D. Carmichael, "Introduction to the Theory of Groups of Finite Order," Boston, U.S.A., and London: Ginn & Co., 1937.

Note.—The cost of printing this contribution has been defrayed by a generous grant from the Rockefeller Foundation for the publication of results of scientific work made to us through the kindness of the National Institute of Sciences, India.—*Ed.*

ABNORMALLY DRY AND WET WESTERN DISTURBANCES OVER NORTH INDIA

BY S. L. MALURKAR

(*Poona 5*)

WESTERN disturbances which produce rain in winter months in N.W. India are of great importance in agriculture, particularly for wheat in the Punjab. Some of the western disturbances give well-disturbed and abundant rain over the area, while others pass away without giving appreciable rain or even go dry. The obvious mode of explanation of the difference, by the insufficiency of moisture supply, begs the question to a certain extent. Upper air circulations due to the two western disturbances may *at first sight* appear to be similar (particularly when the extent of the weather charts is limited); but the resulting effects are widely different. A criterion was arrived at and used by the author for help in furnishing medium-range forecasts to agriculturists and aviators who need short-range forecasts.[1]

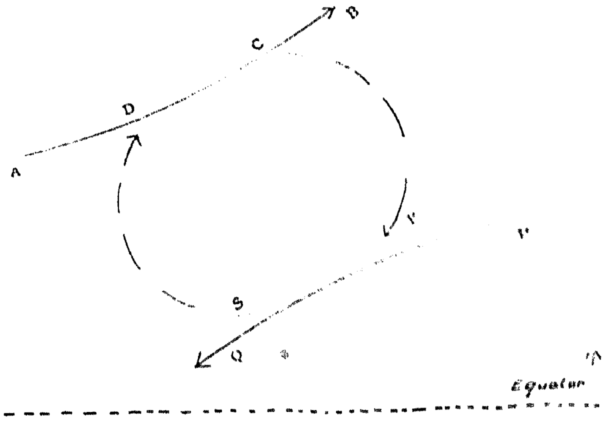
Western disturbances over India are due to the passage of complex low pressure areas or waves over North India under the influence of extra-tropical depressions. These areas, if dealt as such, are not easily understandable either as regards their effects or their motion. A simple method would be to treat the complex low pressure area as composed of a number of simple low pressure areas or successive secondaries with distinct identity and circulation.[2] All these secondary low pressure areas travel in an almost east-northeasterly direction, and in the course of the travel one or more of them may fill up or sometimes intensify. The upper air circulation and rain are due to the combined or resulting effect of the various secondaries at a place. When a primary extra-tropical cyclone passes at a higher latitude, the secondaries form at certain places, which are favoured by orography and the distribution of land and sea.[3] Some of these favoured places (with reference to India) are: the coastal region west of the Nile river; upper of south Egypt; Sudan and Red Sea; Gulf of Aden and the Oman Peninsula; North Arabian Sea off Mekran; East Arabian Sea off Kathiawar and Konkan; and occasionally the head of the Bay of Bengal. The lesser component of earth's rotation in the tropics compared with the higher latitudes probably needs that the secondaries form only when favoured by orography. The secondaries that develop in lower latitudes

(Sudan, Red Sea, off Mekran or off Konkan) affect India, and lack of rain in N.W. India would mean that the particular secondaries were not fully developed.

In the first three or four days of April 1944, a very active western disturbance passed over N.W. India and the rain it produced resembled a day when the S.W. monsoon extends to N.W. India. But it dried up in the course of the next couple of days and hardly showed the activity in N.E. India which one expected. From the clouding and other features, the disturbance could be located in Deltaic China on the 8th. In South Indian Ocean east of Madagascar, a deep depression was found on 7th, and it had moved from the east. Similarly in January 1945, the rainfall which was fairly good in N.W. India during the first ten days of the month fell off rapidly, and simultaneously a depression could be located in S. Indian Ocean. Due to depressions in S. Indian Ocean which formed in quick succession and moved westwards, there was a dry spell over N.W. India during the greater part of the next four or five weeks. It was, therefore, deduced that western disturbances were not quite active or even passed dry when there was a deep depression south of the equator (but not too far south and not widely separated in longitude)[1] or when the seasonal low pressure area south of the equator was more marked than usual. A tentative explanation of the mechanism involved in drying up the northern disturbance based on divergence and subsidence was given.[4] The dynamics of the process can now be given in relation to other known phenomena.

Just north of the equator, in the lower levels of the atmosphere, there is an easterly or east-northeasterly flow of air (N.E. Trades). At higher latitudes, there is a westerly or west-southwesterly stream. (The higher levels are not immediately under consideration.) The easterly winds become stronger when fresh 'pulses' or low pressure areas travel from the east and cross the equator to feed a southern cyclonic storm or a depression. The westerly winds at higher latitudes feed into the western disturbances or their secondaries as tropical air (T) and may strengthen (see Fig. PQ easterly, AB west-southwesterly). When there is such a juxtaposition in the northern hemisphere—an easterly at a lower latitude and a westerly at a higher latitude—the high pressure area in between divides itself into cells of high pressure, or a series of anticyclones. When there is no disturbance to the north or south of it, the anticyclone may be described as stationary in intensity and in approximate position (CRSD). The subsidence would be small and the air in it generally stable.

If the wind stream PQ becomes stronger due to a cyclonic storm south of the equator and the passage of 'pulses' from north to the southern hemisphere, the anticyclone becomes a developing or an increasing one. There would be a tendency for an increased flow of air along CR. The flow along SD may also be slightly increased, but as the passage of 'pulses' is almost *explosive* across the equator (shown by the squalls and thunderstorms) this point may be considered later. For the stream AB, the increased flow along CR would mean



divergence, one an actual due to separation from the original stream and the other one due to descent in latitude. Due to these two effects, the air gets very stable. As the rate of subsidence is greater in a developing anticyclone than in a stationary one as shown by Napier Shaw, the air in the anticyclone would be greatly stabilised. If there be a secondary of a western disturbance to which the stream AB is feeding, both the currents CB and CR speed up and may result in greater divergence. When N.E. Trades get stronger due to the fact that 'pulses' *are* feeding into a southern tropical cyclonic storm or depression or due to an intensification of the southern monsoon low, the air mass (along AB) that would normally have gone to feed the secondary of a western disturbance is attaining great stability and produces little weather in the shape of precipitation. If the southern depression is too far south of the equator (when no 'pulses' feed it from the north), or when it is widely separated longitudinally, the effect on the particular anticyclonic cell would be less, and it can be assumed that the western disturbance is not being affected from the southern hemisphere.

Regarding subsidence on a large scale in Peninsular India, the surface observations at the higher hill stations (Dodda-betta, Coonoor, Kodaikanal) show it by the very low humidities observed on some winter days there.[5] Hahn[6] has given instances of very low humidity at hill stations in Dutch East Indies (Sumatra, Java, etc.). With the help of Radiosonde observations in these days, it is possible to actually notice subsidence at higher levels of the atmosphere over a wider area. There would not be any definite time sequence in the subsidence observation. The dot diagram[5] connecting the extreme dryness at Kodaikanal and the inversion layer at Poona (found by sounding balloons) is almost contemporaneous.

The sudden clearing up of the sky in Central parts of India when there is a depression south of the equator is so striking that a forecaster with a big chart can hardly escape noticing it.

Regarding the increased flow along SD due to the developing anticyclonic cell, though there is divergence in the easterly stream, there is also a latitudinal convergence as it is gaining in latitude. It is likely that some weather can be expected to the west of the